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CITRUS INVESTIGATIONS

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CONTENTS

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CITRUS INVESTIGATIONS

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DEVELOPMENT OF THE CITRUS INDUSTRY IN THE UNITED STATES

Citrus is the most popular fruit in the United States, where its production exceeds the combined production of the six major deciduous tree fruits. Most Americans live in areas where citrus is not grown; consequently, it must be graded, packed, and shipped for hundreds of miles to the consuming centers. The taste appeal of citrus is universal, and its eye appeal also makes it in demand on festive occasions such as Thanksgiving and Christmas. Moreover, the high vitamin C content of citrus places it among the staple fruits required for healthy children and adults.

Citrus is grown commercially in Florida, California, Texas, Arizona, and Louisiana (fig. 1). The industry's annual income surpasses half a billion dollars. The popularity of citrus has spurred home owners to try pot and greenhouse culture as far north as New York State.

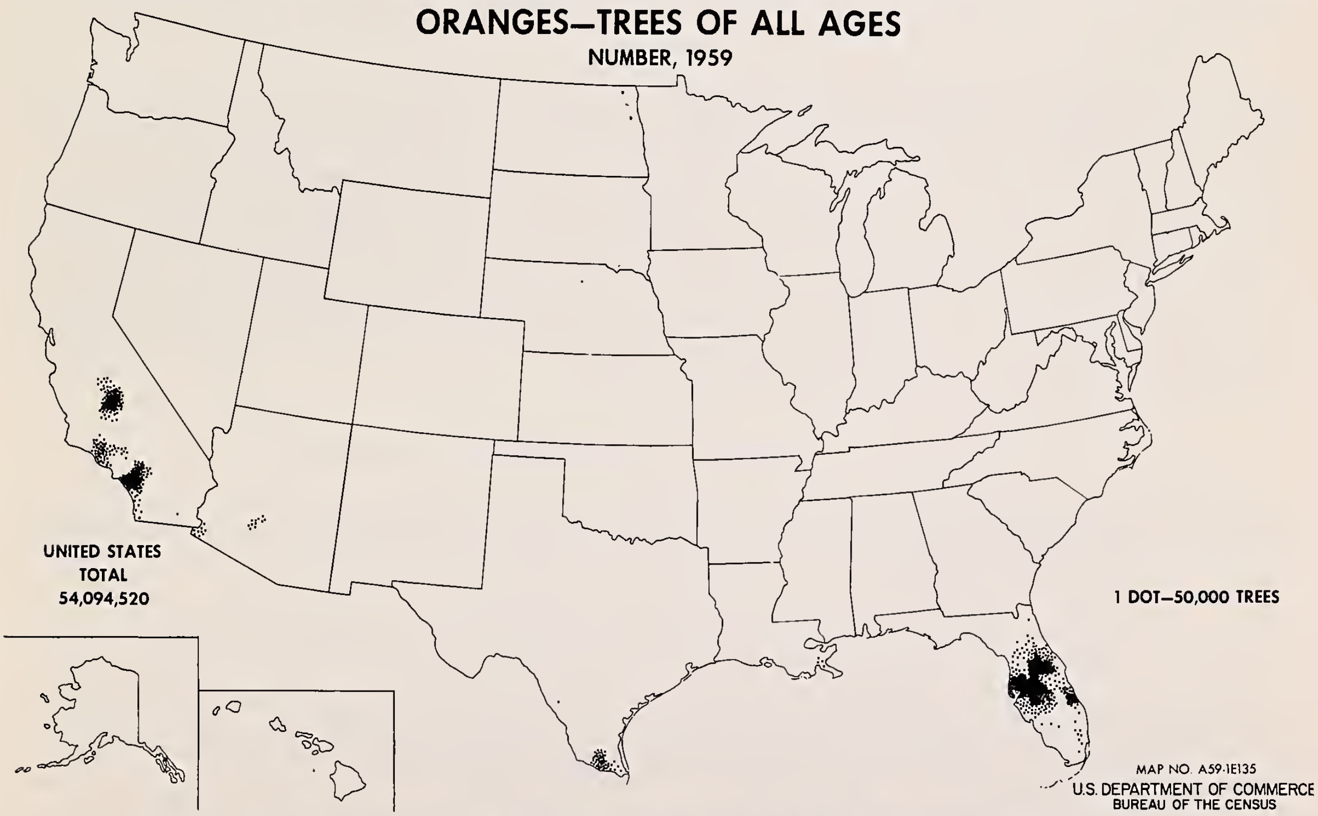

Figure 1.--Map of the United States showing where oranges are grown.

Early History

Citrus is not native to America. Oranges were probably introduced into Florida when St. Augustine was founded in 1565. The early American settlers about two centuries later found, in various parts of Florida, wild seedling orange groves, which probably had developed from seed dropped by the Indians. After Florida was ceded to the United States in 1821, sweet orange (*Citrus sinensis* (Linn.) Osbeck) seedling groves developed rapidly.

Freeze Problem

By 1835, annual production of oranges in Florida was estimated at a million boxes. A severe freeze in 1835 killed most of the orange trees.

A big expansion in the citrus industry in north-central Florida came in the 1870's, with the extensive topworking of wild sour orange (*C. aurantium* Linn.) trees with budwood from the better sweet orange seedling selections. Also, nurserymen began to bud the choice seedling selections to small seedlings of sour orange, sweet orange, and 'Rough' lemon (*C. limon* (Linn.) Burmann) rootstock, and extensive plantings were made of these budded trees. However, the freeze of 1894-95 almost destroyed the citrus crop, which then totaled 6 million boxes, and caused the industry to move southward into Lake, Orange, and Polk Counties.

Commercial citrus culture began in California at about the same time as in Florida. Prior to the 1894-95 freeze, the industry progressed most rapidly in Florida. In 1908-09, Florida again reached a production equaling that of 1894. Meanwhile, California's annual citrus crop averaged approximately 15 million boxes.

Although citrus was grown in Arizona as early as 1700, small commercial groves did not appear until after 1900. In the 1880's, small commercial citrus plantings were started in the delta area below New Orleans, La. In 1910, commercial citrus plantings were begun in the lower Rio Grande Valley of Texas. The severe freezes of 1951 and 1962 retarded the development of the industry in Texas and Louisiana. A severe freeze in 1962 extensively damaged citrus in Florida. However, by this time the industry was scattered over large areas in the central part of Florida, along the Indian River on the east coast from New Smyrna to West Palm Beach, and on the west coast as far south as Fort Myers, and approximately half of the crop escaped injury. Most new plantings since the freeze have gone into the flatwood-type soil in relatively frost-free areas in Indian River, St. Lucie, and Martin Counties.

Large Development of the Industry in Florida

California was the leading orange-producing State for many years, but Florida's output greatly increased during the 1940's. By 1945-46, Florida's orange production was 49,800,000 boxes and California's was 44,010,000 boxes. The development of the frozen orange juice concentrate industry in Florida in 1946 created a new demand for oranges, and this was largely met by increased acreage of oranges in Florida. Since 1946, Florida has steadily increased its lead in orange production, and in the 1960-61 season the crop totaled 86,700,000 boxes (table 1). During the same period urbanization decreased the citrus-growing areas of California and orange production declined to 18,170,000 boxes in 1960-61. California produces most of the lemons and Florida produces most of the grapefruit (*C. paradisi* Macf.).

In the season of 1960-61, $529 million was paid to the citrus growers of the United States for their crop. Packers, shippers, processors, and others in marketing earned additional income. The figures emphasize the financial importance of the crop to the national economy. The citrus industry in Florida has become big business. Large citrus holdings of 1,000 to 10,000 acres have replaced some small holdings of 10 to 100 acres of the early days.

Table 1.--Citrus fruit production and farm value by States for 1960-61 season (modified from U.S. Department of Agriculture Statistical Reporting Service)

Crop and State	Total production	Farm value
	1,000 boxes [1]	Dollars
Oranges:		
Florida	86,700	300,849,000
California	18,170	108,750,000
Texas	3,500	8,505,000
Arizona	955	5,428,800
Louisiana	275	1,003,000
Total	109,600	424,535,800
Grapefruit:		
Florida	31,600	40,764,000
Texas	6,800	7,548,000
California	2,100	3,933,600
Arizona	1,900	2,440,800
Total	42,400	54,686,400
Lemons:		
California	13,600	32,232,000
Arizona	540	2,084,400
Total	14,140	34,316,400
Limes, Florida	310	1,153,200
Tangerines, Florida	4,900	11,515,000
Tangelos, Florida	500	2,715,000
Total for all citrus	171,850	528,921,800

[1] All production figures are based on a 90-pound box for oranges, tangerines, and tangelos; 80-pound box for grapefruit and limes; and 76-pound box for lemons. Production of all varieties of a given species are lumped together.

Citrus Varieties

Most citrus varieties originated as chance seedlings, which have attracted attention because of some especially desirable character. In Florida the approximate percentages of plantings of sweet orange varieties are as follows: 'Valencia' 37, 'Hamlin' 30, 'Pineapple' 21, 'Queen' 6, 'Parson Brown' 3, and 'Washington' navel 1. All these varieties, except the Valencia and Washington navel, originated as chance seedlings in Florida. The Valencia (origin unknown) was probably imported in Florida and California from the Mediterranean area via England around 1870. The Washington navel orange was imported from Brazil via Washington, D.C., in 1870.

Plantings of grapefruit in the United States include 'Duncan,' 'Marsh,' 'Foster,' 'Thompson,' and 'Red Blush' (Ruby). The first two varieties originated as seedlings in Florida and the last three as bud sports. The 'Dancy' tangerine (C. reticulata Blanco) originated as a seedling in Florida in 1867 and is now widely planted in Florida. The 'Temple' orange, considered to be a natural hybrid of tangerine X some other citrus species, was probably imported as budwood from Jamaica and is extensively planted in Florida.

The 'Lisbon' and 'Eureka' varieties of lemons are widely cultivated in California. The Lisbon was imported from Australia. The Eureka originated in California as a superior seedling from seed that had been obtained from imported lemons from Sicily. The large lemon industry in Martin County, Fla., is being developed from the Bearss and Avon seedling selections of imported lemons from Sicily.

Research Agencies

In the development of the citrus industry, research has solved many problems in production, handling, utilization, and marketing. Federal work in the States, in general, has been started in response to appeals from growers and industry organizations for more information than their respective States can provide. Most of the research activities in the U.S. Department of Agriculture are either long-term projects requiring many years to carry out, or projects of broad regional interest including more than one State.

Today the Department's general research program on citrus encompasses production, handling and storage, processing, utilization, statistics, marketing, and cooperative State experiment station work. In this report, only the citrus production research programs of the Fruit and Nut Crops Research Branch and the Crops Protection Branch of the Crops Research Division, Agricultural Research Service, are described in detail. The relationship of these two units to other research agencies in the Department is shown in figure 2.

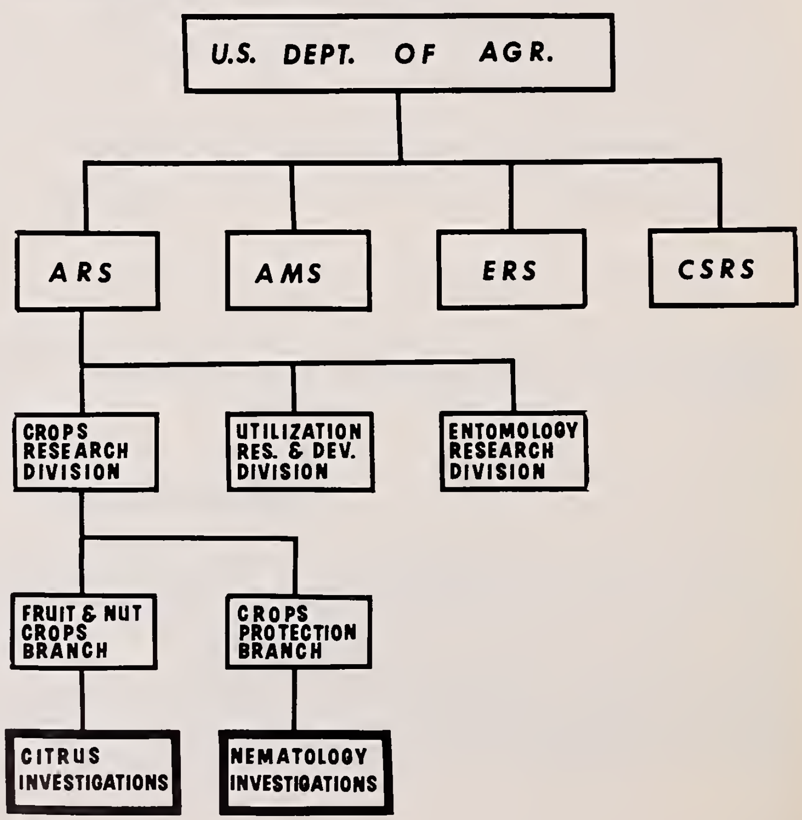

Figure 2.--Organizational chart of research agencies in the Department of Agriculture. ARS indicates Agricultural Research Service; AMS, Agricultural Marketing Service; ERS, Economics Research Service; and CSRS, Cooperative State Research Service. The Citrus Investigations unit is in the Fruit and Nut Crops Research Branch and the Nematology Investigations is in the Crops Protection Research Branch, Crops Research Division, ARS.

The citrus research of the Crops Research Division includes such diverse programs as breeding for better quality fruit and more cold-hardy varieties, controlling diseases by using tolerant rootstocks, improving performance of existing citrus groves through better fertilizer practices, and investigations of nematodes and their control. Breeding, cold hardiness, disease tolerance, and nutrition studies of citrus have been the subject of many scientific papers by Department scientists. In this report several useful discoveries pertaining to these studies and plant nematodes are described.

ABRIDGED HISTORY OF U.S. DEPARTMENT OF AGRICULTURE PRODUCTION RESEARCH, 1880-1964

Prior to 1892, questions from citrus growers were answered by a few Federal scientists in Washington, D.C.

In 1892, the requests for information on citrus "blight" were so urgent that W. T. Swingle and H. J. Webber were sent to Eustis, Fla., to work on this problem and other diseases. The devastating freeze of 1894-95 made disease problems of minor importance, since it killed nearly all trees. Consequently, these men attempted to develop more cold-hardy varieties. They crossed the cold-hardy, but inedible, trifoliate orange (*Poncirus trifoliata* (Linn.) Raf.) with the sweet orange to obtain the citranges. The citranges were cold hardy and resembled an orange, but they also were inedible, as they possessed the bitter acrid flavor of the trifoliate orange. Swingle, T. R. Robinson, and E. M. Savage developed many more new kinds of citrus that have taken their place alongside the standard varieties (fig. 3). A few of the new hybrids, for which they invented names, include citrumelo (trifoliate orange × grapefruit), citrandarin (trifoliate orange × tangerine), citremon (trifoliate orange × lemon), citradia (trifoliate orange × sour orange), tangelo (grapefruit × tangerine), and tangor (tangerine × sweet orange).

The trifoliate orange hybrids had little value as edible fruit, but some became commercial rootstocks. Approximately 65 percent of all recent citrus plantings in California are on 'Troyer' citrange rootstock. The 'Carrizo' citrange is of value in Florida as a rootstock because of its tolerance of the burrowing nematode. The tangelos, on the other hand, produce high-quality edible fruit, and the 'Minneola' and 'Orlando' are important commercial varieties. In the 1960-61 season, production of Orlando tangelos equaled 500,000 boxes in Florida (table 1).

Closely related to the citrus breeding work were investigations of bud variations within orange, grapefruit, tangerine, and lemon varieties from 1911 to 1940. A. D. Shamel and C. S. Pomeroy found bud variations in citrus in California to be common. This finding emphasized the need for careful budwood selection if standard varieties were to be maintained.

Development of control measures for foliage and fruit diseases, such as melanose, scab, and stem-end rot, was performed under J. G. Grossenbacher between 1913 and 1930 at the Department's Citrus Disease Laboratory located at Plymouth, Fla. The laboratory was moved in 1917 to Orlando, Fla., with J. R. Winston in charge of this work.

Swingle and Webber recognized several trunk diseases of citrus, including foot rot, gummosis, and scaly bark. Many of these diseases were present in the old sweet orange and grapefruit seedling groves in Florida. Since gumming was associated with most of these diseases, they were frequently confused with each other. In 1913, H. S. Fawcett identified the fungus *Phytophthora citrophthora* (R. E. Sm. & E. H. Sm.) Leonian as the causal agent of foot rot. In 1934, he identified scaly bark as a virus disease, which he named psorosis. Between 1946 and 1952, T. J. Grant,

Figure 3.--W. T. Swingle (left) and T. R. Robinson sampling hybrid tangelos at Bayacre, Terra Ceia, Fla., December 1941. (Photograph taken by Dr. David Fairchild, noted plant explorer, U.S. Dept. Agr.)

J. F. L. Childs, E. O. Olson, and J. B. Carpenter, in cooperation with experiment station workers in Florida, Texas, and California, discovered the widespread occurrence of tristeza, cachexia (xyloporosis), and exocortis viruses in commercial citrus trees. In trees of some varieties these diseases produced disastrous results.

About 1925, the citrus industry in Florida expanded so rapidly that organic fertilizer supplies were inadequate for the nutritional needs of the trees. Thus the use of inorganic fertilizers increased. They supplied nitrogen (N), potassium (K), and phosphorus (P). By the early 1930's, many citrus trees became chlorotic and were in poor condition. After 4 or 5 years' research, citrus experiment station workers at Lake Alfred, Fla., found that the chlorotic trees were

deficient in magnesium (Mg), copper (Cu), and zinc (Zn). In 1927, G. M. Bahrt at Orlando, Fla., began research on the relationship of soil fertility to citrus chlorosis. He found that manganese (Mn) deficiency existed in many Florida citrus trees. In 1937, A. F. Camp at Lake Alfred, organized the "complete" program of 3-8-8-3-1-1 (N, K, P + Mg, Cu, Zn, and Mn), with Mg, Cu, and Mn added in the dry mix and Cu, Mn, and Zn applied once a year as a nutritional spray. This program was used for 15 years with only minor changes in the N and K. Research by P. F. Smith and W. Reuther in 1950-58, however, showed that heavy applications of P were not necessary, that more N and less K than commonly used were beneficial, that boron should be used regularly, and that toxicity to roots resulted from continued heavy applications of Cu.

Whereas fertilizer is the major cost item in citrus production in Florida, irrigation water is the major item in California citrus production. From 1932-40, studies on water relations of citrus were conducted at Pomona, Calif., by J. R. Furr. It was the first extensive work in this field and demonstrated some fallacies in the theory that soil moisture is equally available throughout the available range from field capacity to the wilting point. This early work proved of immense value to soil physicists at the U.S. Salinity Laboratory, Riverside, Calif., where further research along these lines was conducted.

By the early 1930's, several lines of researchon citrus production problems were underway in California and Florida. Between 1937 and 1940, breeding, nutrition, disease, and irrigation research were coordinated as a single work project, with headquarters at Orlando, Fla. H. P. Traub was in charge of this citrus project from 1937 to 1940, F. E. Gardner from 1940 to 1956, L. C. Cochran from 1956 to 1959, and W. C. Cooper from 1959 to the present (1964). In 1946, all citrus production work in California was transferred to the U.S. Dáte and Citrus Station at Indio, Calif. Also in 1946, work on citrus rootstocks was undertaken at Weslaco, Tex.

In 1960, the citrus production research, except that on nematodes, was designated as the Citrus and Subtropical Fruit Investigations, with headquarters at the U.S. Horticultural Field Station, Orlando (figs. 4 and 5). Research on citrus at the Orlando laboratory is coordinated with that of two other laboratories--U.S. Date and Citrus Station at Indio (fig. 6) and U.S. Fruit,

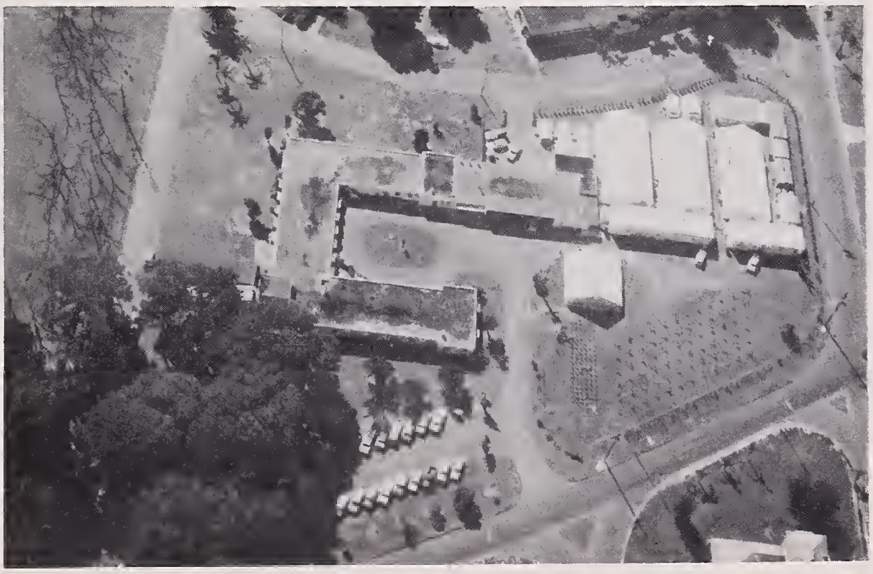

Figure 4.--U.S. Horticultural Field Station, Orlando, Fla., showing laboratory, greenhouse-headhouse area, and citrus nutrition sand culture plots (adjacent to greenhouse area).

Figure 5.--Front view of laboratory of U.S. Horticultural Field Station, Orlando, Fla. Ten research scientists in Citrus Investigations and two in Nematology Investigations work here. The laboratory also houses citrus research personnel in the Entomology Research Division and Market Quality Research Division (ARS).

Figure 6.--U.S. Date and Citrus Station, Indio, Calif. The citrus work is conducted by three research scientists. This building is also headquarters for research on dates.

Vegetable, Soil and Water Research Laboratory at Weslaco (fig. 7). Research on nematodes affecting citrus is conducted at Orlando, Tempe, Ariz., and Weslaco as a part of the Nematology Investigations, Crops Research Division.

Figure 7.--U.S. Fruit, Vegetable, Soil and Water Research Laboratory, Weslaco, Tex. Three research scientists in Citrus Investigations and one in Nematology Investigations work here. The laboratory also houses personnel doing research on soil and water conservation, weed control, and vegetables.

LINES OF RESEARCH IN CITRUS INVESTIGATIONS, 1964

The principal objective of the current Citrus Investigations program is to produce improved scion and improved rootstock varieties of sweet oranges, tangerines, tangelos, grapefruit, limes, and lemons and to produce hybrids of several species. They should have the maximum ability to tolerate such citrus-production hazards as diseases, freezes, and various soil conditions while maintaining high production of high-quality fruit. Tangerines, tangelos, and sweet oranges for fresh-fruit purposes should be easy peeling (see fig. 14).

The breeding program requires guidance from other sciences. The breeder needs the pathologist to determine the nature and cause of diseases and to develop methods of testing disease tolerance in the hybrid seedlings. To determine whether progenies are truly cold hardy, the breeder needs to know whether cold hardiness depends on dormancy or some other physiological function. He, therefore, needs the physiologist to determine these facts and also the basic facts regarding the physiology of salt tolerance. To determine the inheritance of fruit quality traits in progeny, the breeder needs to know the basic facts on the formation and metabolism of acids and sugars that comprise good quality. The mineral nutrition requirements are also being explored of existing commercial citrus varieties and of varieties newly released from the breeding program.

Breeding and Selection of New Scion Varieties

The process of developing new scion varieties through breeding is described in the following five steps:

1. Variety Collection.--A requirement for rapid progress in breeding is to have a source of breeding material available. The collection of 700 citrus selections at Orlando, Fla., and the

smaller but useful collections at Indio, Calif., and Weslaco, Tex., include many of the hybrid varieties produced in the early citrus breeding program of Swingle, Robinson, and Savage. They also include many seedling trees grown from seed sent from far-distant citrus areas. These citrus collections represent a storehouse of genetic characters, which are available for hybridization work at all three stations.

2. Selection of Parent Varieties.--Basic exploratory work is being conducted, or is planned, to determine which parents are likely to produce fruits of certain specialized types. Some selections that have no value for commercial production but have certain characters, such as large fruit, brilliant color, seedlessness, or a combination of several desirable, outstanding traits, are tested for transmission of these traits. That such material can be very useful is illustrated by the results of a cross between 'Umatilla' (C. reticulata × C. sinensis), a large, attractive, and nearly seedless fruit but of poor quality, and the 'Honey' (C. reticulata) tangerine, a small, poorly colored, and seedy fruit but of high quality. This cross produced a high proportion of good progeny.

Most named varieties of citrus, except pummelos (C. grandis (Linn.) Osbeck) and lemons, produce seed containing mostly nucellar (asexual) embryos. Nucellar embryos produce seedlings that "come true from the seed parent." Nucellar embryony has greatly limited the choice of seed parents from which a fairly good yield of hybrid seedlings could be expected. A few varieties such as 'Clementine' tangerine and Temple orange, however, produce seed containing only sexual embryos. These two varieties are excellent seed parents in that they produce 100-percent hybrid seedlings and many of these have outstanding merit. Dissection of a sample of seed produced by a variety reveals whether, if used as a seed parent, it will produce only hybrid seedlings or only nucellars or a mixture of the two. This method makes possible judicious selection of seed parents.

3. Hybridization.--The various characters of the pollen parent are combined with those of the seed parent by hybridization. The pollen sacs of buds almost ready to open are removed and pollen from the desired male is applied by hand (figs. 8 and 9). The crosses are made wherever the plant materials are availabge, and seeds are sent to where the trees are to be grown and evaluated.

4. Evaluation of Hybrid Progeny.--The hybrid seedlings are planted with close spacing in the field and grown as rapidly as possible to fruiting. Usually 3 to 8 years is required under favorable conditions. As the hybrids fruit, the best trees are selected for additional tests. Hybrid seedlings are evaluated on various breeding farms such as Foundation Farm near Leesburg, Fla. (fig. 10). The best selections from the first evaluation are propagated on several rootstocks and fruited to find selections superior to existing commercial varieties.

Figure 8.--Collecting pollen from citrus flowers for making crosses. (Indio, Calif.)

Figure 9.--Pollinating citrus at Orlando, Fla.

Figure 10.--Seedlings being grown to fruiting age at Foundation Farm. This 200-acre farm was leased for 99 years at no cost to the U.S. Department of Agriculture by the Florida Citrus Research Foundation.

Attractiveness of the fruit depends primarily on size and color. The object of the breeding program for superior varieties for the fresh-fruit market is to produce fruit with an orange-red rind, characteristic of the Washington navel orange grown in California or the Dancy tangerine grown in either Florida or California. Extensive hybridization of tangerine and tangerine hybrid varieties with sweet orange varieties has yielded a high proportion of hybrid seedlings with an orange-red rind. It appears possible that sweet orange hybrids can be produced that look like sweet oranges, but which have a deeper orange-red rind and are more attractive than the present commercially grown sweet orange varieties such as Hamlin and Valencia.

Internal quality of citrus is a highly complex problem. Sugars constitute the bulk of the soluble solids in the juice; other components include citric, malic, and other organic acids, very small amounts of inorganic salts, and minute amounts of esters.

Although the distinct flavor of the different citrus varieties is chiefly due to their characteristic volatile esters, a pleasing taste is generally considered to be dependent on the relative amounts of sugars and acid in the juice. Glycosides are also a factor in the bitter taste of some grapefruit. Sweet oranges as a group have a sweet taste, grapefruit, a sprightly acid taste with varying degrees of bitterness, and tangelos, a sprightly acid taste with little to no bitterness. Extensive research has shown that no particular sugar content alone will assure acceptable taste. The so-called acidless orange, 'Succory,' is unpalatable to our taste but relished by some people in the Middle East. The consumer's preferred tastes range from sweet to pleasantly tart and require certain proportions of sugar to acid.

The large populations of progenies in the current citrus breeding program have made it necessary for the fruit breeder to test fruit quality by a taste test in the field. By this simple procedure he can select a few high-quality hybrids out of a thousand or more. Although this procedure is effective in selecting varieties, it fails to give quantitative data on inheritance of acidity and sweetness.

Although citric acid is the chief organic acid component of mature orange fruits, malic acid is the chief component of pea-sized fruit just after fruit set. Knowledge is needed on the formation and metabolism of acids and sugars in the so-called acidless, low-acid, and high-acid types and the inheritance of these types in the progeny of particular crosses. A program is now underway to study the effect of heredity and climate on the formation and metabolism of both acids and sugars in citrus from fruit set to maturity (figs. 11 and 12).

5. <u>Release of Varieties</u>.--Superior selections are described and released as new varieties. Three new varieties--'Robinson,' 'Osceola,' and 'Lee' tangerine hybrids--originated from a cross of Clementine tangerine X Orlando tangelo and were released in Florida in 1960 (fig. 13).

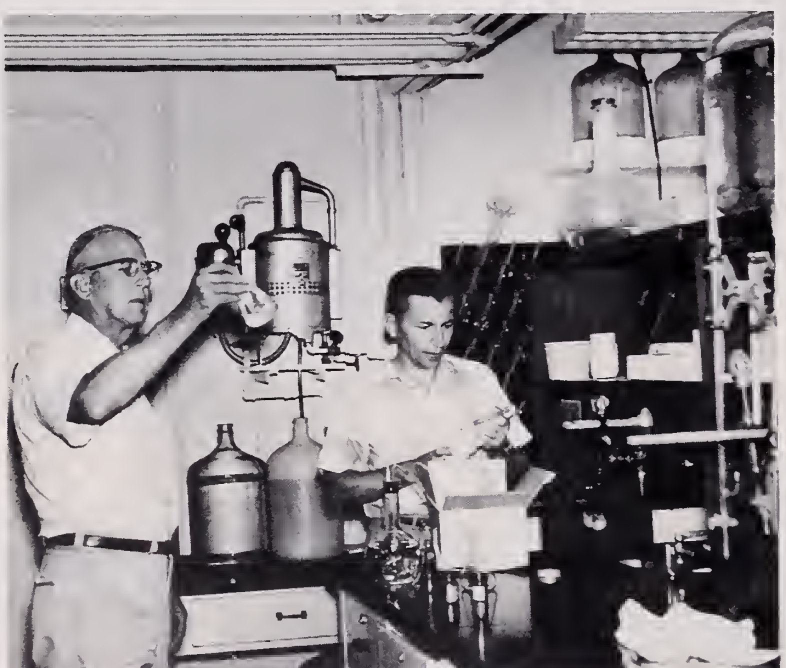

Figure 11.--Fruit analysis laboratory at Orlando, Fla.

Figure 12.--Nitrogen fraction collector in biochemistry laboratory at Orlando, Fla.

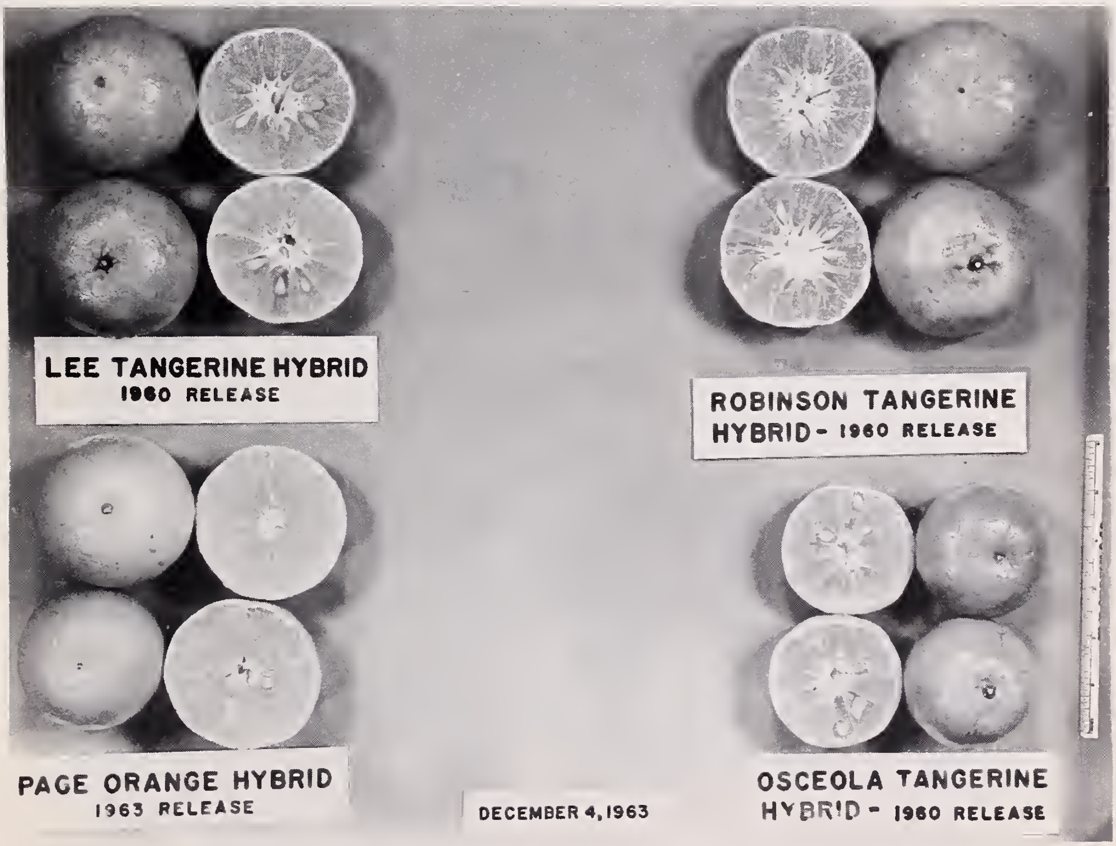

Figure 13.--Fruits of four new varieties released in Florida.

These new tangerine hybrids ripen earlier than commercially grown Dancy tangerines in Florida. Another new variety--'Page' orange hybrid--originated from a cross of Minneola tangelo X Clementine tangerine and was released in Florida in 1963. The tree and foliage of the Page closely resemble those of a sweet orange. Also the fruit resembles an orange in size and shape. The rind and flesh are a deep reddish orange similar to those of the seed parent Minneola tangelo. The rind is free peeling but is not loose (fig. 14). The Page ripens early and is of higher quality than the early-ripening Hamlin and Parson Brown sweet oranges in Florida.

New tangerine-hybrid varieties released in California in 1964 are 'Fairchild,' a cross of Clementine tangerine X Orlando tangelo; 'Fremont,' a cross of Clementine X 'Ponkan'; and 'Fortune,' a cross of Clementine X Dancy tangerine (fig. 15). In the Coachella and Imperial Valleys of California the Fairchild is early ripening, the Fremont is midseason, and the Fortune is late ripening. These varieties are superior in some respects to the Clementine and Dancy tangerines.

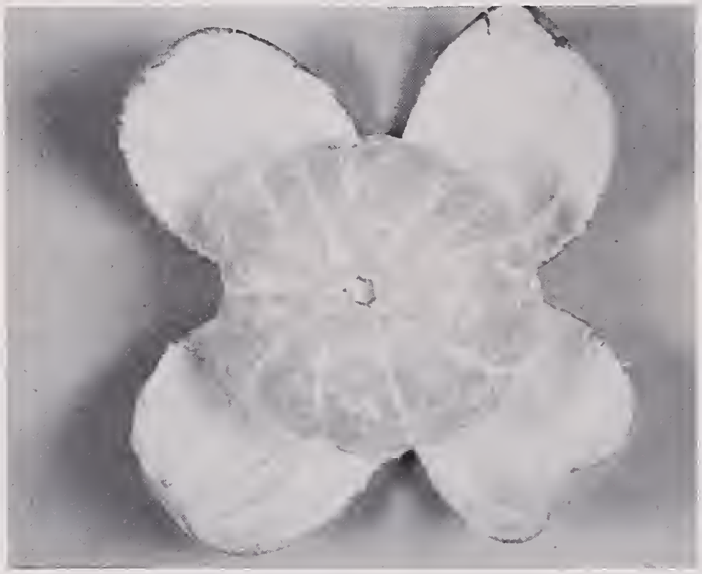

Figure 14.--Free-peeling characteristic of the Page variety.

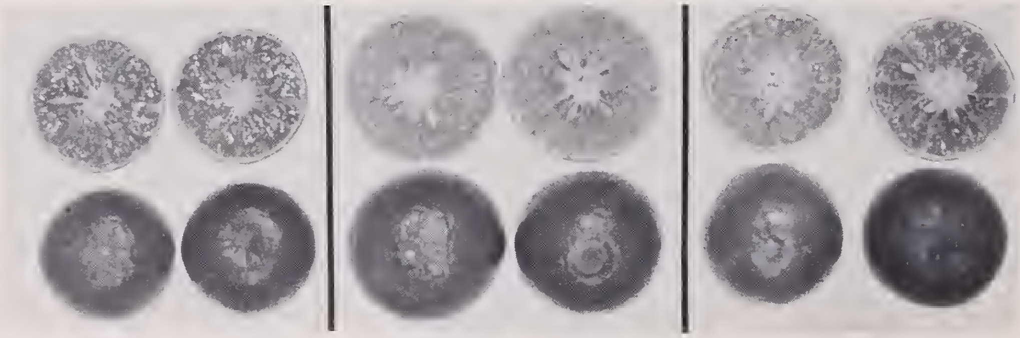

Figure 15.--Fruits of three new tangerine-hybrid varieties released in California: Left to right, Fremont, Fortune, and Fairchild.

Producing new varieties, through breeding, of a perennial fruit crop such as citrus requires a minimum of 10 years from the time of hybridization to the release of the variety to the industry. Even after a new variety is released, 10 or more years of grower evaluation of the variety is required before its potentialities as a new commercial variety are fully determined. Not all new varieties attain commercial importance. The Orlando tangelo, released by Swingle, Robinson, and Savage in 1931, has been grown commercially only since 1950, but the 'Perrine' lemon (C. aurantifolia Swingle X C. limon), also released in 1931, did not show good orchard performance under grower testing and therefore never attained commercial importance.

Breeding and Evaluation of New Rootstock Varieties

Different rootstock varieties possess specific tolerances of diseases, low temperatures, poor drainage, and salinity. These characters affect the adaptability of the budded tree to certain soil and climatic situations. Extensive hybridization work with rootstock varieties possessing various tolerances is underway, with the object of developing a series of rootstock types that will combine disease, salt, and cold tolerance and produce high-quality fruit.

The rootstock program is designed to find rootstock varieties that have no major weakness when grown in the field under specific soil and climatic situations. Laboratory and greenhouse tests can provide information on the probable adaptability of a given rootstock variety to given soil and climatic conditions. However, the final evaluation with regard to rootstock effect on tree growth, production, and quality of fruit on the scion variety must be determined by field tests (fig. 16). Field testing of new rootstocks may require as much as 20 years to evaluate each planting. During this period, records of growth, yield, and fruit quality are maintained. Because rootstock plantings require large areas and much care, most of the work is cooperative with commercial citrus growers, who furnish grove care, own the trees and fruit, and permit Department of Agriculture personnel to obtain growth, yield, and fruit-quality data. The Department supplies the trees on the various rootstocks.

Figure 16.--Young citrus rootstock planting at Windermere, Fla.

Diseases

Many diseases constantly hamper citrus production by killing roots, branches, or fruit, reducing yield and quality, or otherwise harming the citrus trees or fruit or both. Those diseases of economic importance to the industry include foot rot, tristeza and other virus diseases, blight, stubborn, spreading decline, and slow decline.

Foot Rot.--Foot rot is a disease of the bark on the lower trunk and crown roots of citrus trees caused by the fungus *Phytophthora* spp. (fig. 17). A less conspicuous but equally destructive phase of infection by the fungus includes rotting of the feeder-root system, sometimes named *Phytophthora* root rot. The fungus is present in all citrus-growing areas of the United States. It can be spread by infected nursery stock or by infected soil and water. The disease is often fatal to trees on susceptible rootstocks, such as sweet orange and Rough lemon. Many thousands of trees in all citrus-growing areas are lost annually and many more are seriously weakened by attacks of this fungus; thus a serious loss in fruit production results.

Rootstocks that are commercially acceptable and yet resistant to infection by *Phytophthora* spp. offer the best means of foot rot control. Unfortunately sour orange, one of the most tolerant of the commercial rootstocks, is damaged by the tristeza virus disease. The trifoliate orange and Yuma selection of citrange are tolerant of tristeza and show resistance to *Phytophthora* infection, but they are intolerant of salt and of burrowing nematodes. Salt-tolerant rootstocks are desirable for citrus in the Southwest and burrowing nematode-tolerant rootstocks are needed for Florida. Hybridization work is underway using trifoliate orange and Yuma selection of citrange as sources of foot rot tolerance. The progenies of these crosses are tested for tolerance to the fungus by inoculating the seedling trees with *Phytophthora* spp. in an aerated water bath (fig. 18), followed by growth studies and observations in incubation beds and field plots.

Figure 17.--Foot-rot lesion at bud union of a 20-year-old Valencia orange tree on Rough lemon rootstock. (Orlando, Fla.)

Tristeza and Other Virus Diseases.--Tristeza is a virus disease of citrus that has caused very serious damage in several citrus-growing areas throughout the world. Most damage has occurred to sweet orange trees growing on sour orange rootstocks, a scion-rootstock combination that is intolerant of tristeza. The virus causes a necrosis of the phloem (bark) tissue at the bud union and thereby disrupts translocation processes in the tree. This results in a deterioration of the feeder roots and the eventual decline of the tree. Vein-clearing leaf symptoms are characteristic of this disease (fig. 19). Decline symptoms may occur slowly or rapidly,

Figure 18.--Aerated water-bath technique for inoculating citrus seedlings with Phytophthora spp. (Indio, Calif.)

Figure 19.--Vein-clearing leaf symptoms of tristeza virus: A, mild strain virus, B, severe strain, and C, control. (Orlando, Fla.)

depending on the virus strain or strain mixtures, the variety of scion and rootstock, and unfavorable environmental factors such as excessive or deficient soil moisture. Trees in many areas are killed quite rapidly after infection occurs. However, in other areas, particularly in Florida where mild strains of tristeza predominate, susceptible trees may carry the virus for long periods with no visible effect. Although the greatest losses have occurred with sweet orange on sour orange rootstocks, certain other scion and rootstock combinations are susceptible.

The tristeza virus may spread from tree to tree by budding and by means of certain insect species, which carry and transmit the virus. In South America the disease destroyed 20 million trees in 20 years. Losses in the United States have been severe only in California, but the tristeza virus is present in some citrus trees in Florida, Louisiana, Arizona, and Texas. It could possibly be a serious hazard to susceptible trees in those States in the future.

A widely used test plant for determining the presence of tristeza virus in citrus trees is the 'Mexican' lime (C. aurantifolia). It is especially sensitive to tristeza and is therefore a quick indicator plant. Budwood carrying tristeza can be freed of the virus by heat treatment.

The most effective way to control tristeza disease is to use tristeza-tolerant rootstocks. Research workers in Brazil and California discovered that the following citrus trees are tolerant of tristeza disease: sweet orange, Rough lemon, trifoliate orange, 'Rangpur' lime, and Troyer, 'Rusk,' 'Savage,' and Carrizo citranges. A program is underway to test new selected hybrids and rootstocks for tolerance of the severe strain of tristeza virus that is damaging to citrus in Florida.

Virologists have identified eight other citrus viruses, which can be detected in trees by suitable indicator plants. Those known to be widespread in commercial citrus plantings and which are transmitted from tree to tree only by buds are cachexia (xyloporosis) (fig. 20), exocortis, and psorosis. These findings are the basis for effective virus-free budwood certification programs to control these three viruses in Florida, Texas, California, and elsewhere. Certain rootstocks are known to be tolerant of one or more of these viruses. Unfortunately many citrus varieties tolerant of insect-transmitted tristeza are not tolerant of cachexia and exocortis or both. Consequently, it is necessary to use budwood that is free of these two viruses to take advantage of tolerances of certain rootstocks to tristeza.

Figure 20.--Inspecting Orlando tangelo seedling for pitting symptom of cachexia. (Weslaco, Tex.)

No citrus virus disease is known to be seedborne. Since nucellar seedlings "come true from seed" and are virus free, their use provides a means to eliminate viruses carried in a variety. Most seedlings of sweet orange, grapefruit, and tangerine varieties are nucellar. Some varieties, however, produce no nucellar seedlings; consequently, there are no known virus-free source trees of these varieties.

The major problem with nucellar seedling selections is the scarcity of orchard performance records for many of them. Virus-free nucellar trees are of questionable value if they are not as productive of high-quality fruit as the old lines they replace. They must, therefore, be tested for production characters before release for commercial use.

Blight and Stubborn.--Blight kills more citrus trees each year in Florida than any other disease except foot rot. Pathologists have investigated blight sporadically since 1880 and the cause of the disease has not yet been clearly established. There seems to be no special susceptibility or tolerance among the rootstocks in common use.

Stubborn is a disease of citrus that is most noticeable on trees in desert areas. The visible symptoms include retarded growth, multiple buds, short internodes, bushy growth habit, leaves cupped and smaller than normal, and fruits acorn shaped, lopsided, and small. Ripening fruits may remain green at the stylar end and infected fruit of some varieties have a blue albedo. The disease is transmissible by grafting.

Spreading Decline.--Spreading decline is attributed to the burrowing nematode (Radopholis similis (Cobb) Thorne) or to a complex of the burrowing nematode and a fungus (Fusarium spp.). The disease spreads through a grove causing a rather rapid deterioration of feeder roots. Affected trees show such symptoms as chlorosis, abnormally small leaves, water stress, stunted growth, and reduced fruit yield. To date, Florida is the only citrus area in the United States known to be plagued by the burrowing nematode. Using rootstocks tolerant of burrowing nematodes appears to be the most effective way to combat the disease. Cooperative research in this field is being conducted at the citrus experiment station, Lake Alfred, Fla.

Citrus seedlings are tested for tolerance of the burrowing nematode by growing them for a few weeks in nematode-infested soil (in tanks). The routine testing of seedlings of thousands of citrus varieties has shown that tolerance of the burrowing nematode exists in Carrizo citrange and in certain selections of Rough lemon and sweet orange (fig. 21).

Figure 21.--Burrowing nematode-susceptible Pineapple orange (left) and burrowing nematode-tolerant 'Ridge Pineapple' orange. Both were grown for 9 months in nematode-infested soil at Orlando, Fla.

Slow Decline.--Another disease of citrus, sometimes referred to as "slow decline," is caused by the citrus nematode *Tylenchulus semipenetrans* Cobb. This nematode occurs commonly in all citrus-producing States and is a potential hazard to citrus production. Plans are now being developed to test selected rootstock hybrids for resistance to this nematode. The technique used is similar to that used for the burrowing nematode. In the citrus nematode test the seedlings are grown in the tank for at least 6 months, as compared with only 6 to 8 weeks for the burrowing nematode test.

The citrus nematode is being controlled commercially in California and Arizona by application of 2 to 6 gallons of the nematocide 1,2-dibromo-3-chloropropane (DBCP) per acre applied in about 5 acre-inches of irrigation water.[1] This kills most of the nematodes on and around the roots of citrus trees, permitting the trees to grow and produce normally for several years. However, the nematode population builds up again in the treated area. For effective chemical control it is necessary to re-treat every few years. For this reason the best horticultural control lies in the use of nematode-resistant rootstocks.

Nutrition

Successful culture of citrus in all areas is dependent on satisfying the mineral nutritional requirements of the tree. In Florida, where citrus is grown on sandy soils of very low native fertility, the fertilization program is especially important. Basic information is derived from greenhouse and outdoor pot cultures where precise control of mineral feeding is possible (fig. 22). Information gained in this way is further tested in numerous cooperative experiments on growers' property for periods of 10 to 20 years before final conclusions are reached. The effectiveness of different treatments is closely followed by leaf and soil analysis of the various minerals (fig. 23).

Since nutritive elements behave in different ways and affect one another, continuous study is necessary to follow changes that occur slowly in the soil and in the tree. Some elements are needed regularly, some only at intervals, and some seldom or never in the fertilizer program.

Figure 22.--Sand culture experiment on K, Ca, and Mg levels at Orlando, Fla.

Figure 23.--Mineral leaf analysis in nutrition laboratory at Orlando, Fla.

[1] If nematocides are handled or applied improperly, or if unused parts are disposed of improperly, they may be injurious to humans, domestic animals, desirable plants, pollinating insects, fish, or other wildlife, and may contaminate water supplies. Handle these chemicals with care. Follow the directions and heed all precautions on the container label.

The testing of new materials, new ways of application, and new methods of timing the applications on a slow-growing tree causes nutritional research to be a never-ending effort.

The amount of rainfall, irrigation practices, salinity problems, and soil texture all affect nutrient availability. Studies must be extended to new areas being planted to citrus in order to solve the problems encountered under different conditions.

Salinity

Supplemental water is necessary for successful agriculture in Arizona, California, and Texas. Colorado River water, carrying soluble salts ranging from 100 to 750 p.p.m., is used for irrigation in California and Arizona, and Rio Grande River water, carrying soluble salts ranging from 500 to 5,000 p.p.m., is used for irrigation in Texas. During periods of drought in Texas, well water is used in place of river water and such well water often contains from 2,000 to 5,000 p.p.m. of soluble salts. Excessive salts cause burning of foliage and root injury. Some varieties of citrus tolerate more salt than others; therefore, certain rootstocks can be used in soils containing excessive salts, whereas others cannot. Salt tolerance and sometimes boron tolerance are essential for trees in many irrigated sections of Arizona, California, and Texas.

U.S. Department of Agriculture workers have shown that rootstocks profoundly affect salt accumulation in the tree and that trees grown on salty land usually recover poorly from freezes. Various rootstock-scion combinations are tested in field plots that are flooded with irrigation water carrying varying amounts of different salts separately and in combination. These are referred to as "salt-tolerance plots" (fig. 24). The most salt-tolerant rootstocks include Rangpur lime, 'Cleopatra' tangerine, *Severinia buxifolia* (Poir.), and *Eremocitrus glauca* (Lindl.) Swingle.

Figure 24.--Salt tolerance plots at Indio, Calif.

Cold Hardiness

No disease or soil condition is as devastating to the citrus industry as a major freeze. Freezes are a recurrent hazard that cannot be eliminated in citrus-growing areas in the United States. They cause heavy economic loss to the inidividual grower and are a major threat to the stability of the citrus industry.

Certain trees often show little or no injury from a freeze that severely injures nearby trees. The ability of a tree to withstand freezes is affected by the weather preceding the freeze and by the temperature at which the tree (both scion and rootstock varieties) becomes dormant. The tree may become dormant at 50° F., but if the temperature preceding a freeze is above 60°, the tree will not be fully dormant. Whether maximum cold hardiness is obtained from complete dormancy is not known. If true cold hardening exists, its maximum effect may not be evident until the tree is preconditioned at temperatures just above the freezing point of the tissue. However, the potential cold hardiness of a variety is of little value if the freeze comes when the tree is in an unhardened condition. Freezes in Florida and Texas usually occur when trees are between partial and complete dormancy, and the state of dormancy and cold tolerance are affected by the rootstock variety (fig. 25).

Cold tolerance of citrus has been studied intermittently since 1900, but research has been confined mainly to the effects of natural freezes. In recent years plant physiologists have studied freezes and cold tolerance using controlled temperature rooms and portable units equipped to produce artificial freezes (figs. 26 and 27). Plant material can now be tested experimentally to determine its minimum temperature for growth, its ability to withstand certain prefreeze and freeze conditions likely to occur in particular areas, and its potential maximum cold hardiness.

Climatology

A hybrid desirable for Florida may not necessarily be valuable in Texas and California, because varieties respond differently to changes of climate. Material promising for use in one State is therefore evaluated in the other States to determine its reactions to different climates.

Meteorological instruments have been installed in Valencia orange orchards in the various citrus-growing States to measure the microclimate of the tree (temperatures of leaf, twig, fruit, trunk, and roots) in relation to tree behavior (figs. 28 and 29). These data have provided information on the effect of climate on specific characteristics of the variety such as rind thickness, juiciness, fruit ripening time, and tree dormancy. When this program is expanded to include phenological data on other varieties, such information will aid the breeder in determining which parents are suitable for producing hybrids adaptable for culture in specific climates.

Figure 25.--Damage to Pineapple orange on sour rootstock (A) and on Rough lemon rootstock (B) at Grand Island, Fla., after the December 1962 freeze. (Photo taken June 17, 1963.)

Figure 26.--Citrus cultures in growth chambers at Weslaco, Tex.

Figure 27.--Tree freezer at Weslaco, Tex.

Figure 28.--Sketch showing thermocouples attached to leaves and twigs of a branch of a citrus tree. (Courtesy Agr. Sci. Rev. 2: 42. 1964.)

Figure 29.--Citrus climatological station at Orlando, Fla.

Orlando, Fla.

Through the cooperation of the Florida Research Foundation, 200 acres of land near Leesburg, known as Foundation Farm, has been made available to the U.S. Department of Agriculture for citrus breeding work. The scientific staff working on breeding at the U.S. Horticultural Field Station, Orlando, Fla., has been expanded to include a geneticist, a horticulturist, and a plant physiologist. The Florida Citrus Commission provided funds for fencing, land clearing, and an irrigation system for Foundation Farm. Nucellar seedlings of 700 varieties in the present citrus collection have been planted in a new variety block at this farm. A similar, but smaller, planting of nucellar seedlings of various varieties has also been made at the Blue Goose Farms south of Ft. Pierce. Also, trees propagated from the variety collection at Orlando have been planted at the Consolidated Finance Inc. Farm near Sebring. Thus, reasonable provision has been made to preserve varieties valuable for use as parents in planned hybridization work.

The present activities at Foundation Farm also include the planting of 20 acres of hybrid seedlings for fruiting out. This acreage will be increased both at Foundation Farm and at the Graves Brothers' Farm at Wabasso as new crosses are made. About 2,000 hybrids have been budded to Rough lemon rootstock for planting at Sebring. Trees of 10 of the most promising new hybrids are now being propagated on 10 rootstocks for two 20-acre plantings--one at Foundation Farm and the other on flatwoods soil in Manatee County.

In support of the breeding program, three plant pathologists using greenhouse facilities at the Orlando station are developing methods of testing rootstock seedlings for tolerance of the burrowing nematode, the citrus nematode, foot rot, and tristeza. Facilities are provided at Orlando to permit the plant physiologist in the breeding program to test seedlings for cold hardiness. Thus, a large-scale tolerance testing program is being developed to facilitate the evaluation of rootstock hybrid seedlings.

The present research activities at the Orlando station include a continuation of the nutrition program designed to study the nutritional requirements of citrus varieties, the field evaluation of rootstocks, including 10 large field tests in various parts of the State, basic work on tristeza, blight, and stubborn disease, studies on various soil organisms associated with root rot, biochemical studies on sugars and organic acids in citrus fruits as affected by nutrition, climate, and heredity, and field, laboratory, and greenhouse research on the burrowing, citrus, and other nematodes affecting citrus. Also, measurements of the solar radiation, wind velocity, and temperature and relative humidity of air around the tree in citrus orchards in Florida, Texas, Arizona, and California, started in 1960, are continuing in cooperation with the Universities of Arizona and California and the U.S. Department of Agriculture stations at Indio, Calif., and Weslaco, Tex.

Indio, Calif.

A productive citrus breeding program has been in progress at the U.S. Date and Citrus Station, Indio, Calif., since 1948, and three scientists are working there on citrus. The citrus breeder at Indio has harvested approximately 100,000 seeds of various hybrids since 1961, and approximately one-third of these have been sent to the Orlando station and one-third to the Weslaco station. Most of the hybridization work on rootstocks has been conducted at Indio. The plant physiologist, using the salt-tolerance plot technique developed at Weslaco, has screened a large number of rootstock hybrid seedlings for salt tolerance. The plant pathologist has

developed a method of screening hybrid seedlings for foot rot tolerance and has used this successfully to test thousands of hybrids for foot rot tolerance. The field testing of hybrid seedlings is done at the Indio station, U.S. Southwestern Irrigation Field Station, Brawley, Brock Ranches on the East Mesa near El Centro, and a new 32-acre farm near Indio provided at the U.S. Bureau of Reclamation. The growth of seedlings to fruiting age is particularly rapid at Indio; most of them are bearing fruit in 3 to 5 years.

The present citrus research activities at Indio also include field studies on the cause and nature of stubborn disease and the development of virus-free sources of budwood of various citrus varieties for Arizona.

Weslaco, Tex.

The U.S. Fruit, Vegetable, Soil and Water Research Laboratory at Weslaco, Tex., serves as the base of operations for fundamental work on cold hardiness for the Citrus Investigations. The staff includes a plant pathologist, a plant physiologist, and a chemist. The facilities include a biochemistry laboratory with a setup for radioactive isotope studies, growth chambers that permit control of light and air and soil temperature, and a tree freezer large enough to cover a mature bearing tree. Ample land for experimental plantings is provided at Rio Farms, Inc., 25 miles northeast of Weslaco. Approximately 20 acres of hybrid citrus seedlings are being grown to fruiting at Rio Farms. The hybrid seed is largely from the Indio laboratory and comes from crosses made with the object of producing cold-hardy varieties.

The research activities at Weslaco also include laboratory and field work on salt tolerance and field tests with nucellar line and virus-free old lines of various varieties on different rootstocks. Investigations are also conducted on nematodes affecting citrus.

Tempe, Ariz.

Research at Tempe, Ariz., is confined to studies of nematodes affecting citrus, particularly the citrus nematode. The principal emphasis of the work is on the development of practical methods using DBCP for controlling the citrus nematode in producing groves.

OUTLINE OF RECENT RESEARCH ACCOMPLISHMENTS

Orlando, Fla.

1. Released four hybrid varieties--Robinson, Lee, Osceola (1960), and Page (1963) (see fig. 13).
2. Released three burrowing nematode-tolerant rootstocks in 1964--'Estes Rough' lemon, the 'Milam' lemon, and the Ridge Pineapple. Described in 1962 two additional burrowing nematode-tolerant rootstocks--a selection of the Carrizo citrange and a selection of the Sanguine Grosse Ronde sweet orange. This work was in cooperation with the Citrus Experiment Station at Lake Alfred, Fla.
3. Identified in 1963 strains of *Phytophthora* spp. with varying degrees of virulence.
4. Developed heat-treating method for freeing budwood of tristeza (1960).
5. Transmitted infectious variegation virus mechanically (1962).

6. Developed fundamental information on sampling procedures and optimal leaf composition of minerals. This information has been used in establishing worldwide standards for diagnosis of the nutritional status of citrus (1961).

7. Defined many of the interactions that occur between fertilizer elements, and devised practical means of minimizing their effect through balanced nutrition (1962).

8. Developed a color test for exocortis (1959).

9. Released two nucellar selections of Persian lime (1964).

10. Demonstrated that a fungus of the genus *Fusarium* is associated with the burrowing nematode in "spreading decline," and that control of the fungus produces improvement of citrus trees in the greenhouse and the field without control of the burrowing nematode.

11. Demonstrated that the burrowing nematode under simulated field conditions in the greenhouse moves only a few inches per month at most.

Indio, Calif.

1. Released three hybrid tangerines--Fairchild, Fremont, and Fortune--in 1964 (*see* fig. 15).

2. Showed that salt tolerance is a heritable characteristic in citrus and can be combined in varieties possessing cold hardiness (1963).

3. Developed virus-free citrus varieties for California and Arizona (1960-64).

4. Found that on sandy soils nearly devoid of clay and silt, high frequency of irrigation and nitrogen were needed for the first 3 years to obtain a vigorously growing citrus tree (1963).

5. Found that stubborn disease was widespread in citrus plantings in Arizona and California (1959-63).

6. Developed a method of rapidly detecting exocortis virus in citrus by means of the 'Etrog' citron (*C. medica* Linn.) test plant. This was University of California work in cooperation with the U.S. Department of Agriculture (1963).

Weslaco, Tex.

1. Found that trees injured by chloride accumulation are affected more by cold than trees with no chloride injury (1962).

2. Found that cold tolerance of citrus is associated with tree dormancy (1961).

3. Found that mature bearing trees on Cleopatra tangerine rootstock are more tolerant of cold than trees on sour orange rootstock under saline soil conditions (1962).

4. Developed virus-free budwood of Texas citrus varieties (1961).

5. Showed that cool day and night temperatures are primarily responsible for the induction of dormancy in citrus and that day length is not a major factor (1961).

6. Found that 9-month-old seedlings of known citrus varieties, when induced to become dormant in artificial climates and frozen, behave similarly to the same varieties induced to become dormant and frozen naturally (1961).

Tempe, Ariz.

1. Developed practical method of controlling the citrus nematode in irrigated citrus groves by applying DBCP in about 5 acre-inches of irrigation water.

2. Demonstrated that in the Yuma, Airz., area no advantage is gained by using a nematocide on old citrus soils.

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